

# Neogene stratigraphic development of the Arabian (Persian) Gulf

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## LONG TERM GOALS

Neogene sediments in the Arabian (Persian) Gulf comprise a northeast-thickening wedge (0.1-2.0 km) of clastics shed from the Zagros uplift in Iran. Our long-term goal is to understand how variations in source, tectonic subsidence, climate, and sea level affected sedimentary processes and stratigraphic development of an arid, shallow-marine environment.

## OBJECTIVES

Our objectives include mapping Quaternary channels, deltas, and sequence stratigraphy across the entire basin and correlating these to wells and surface sediment cores. These data will be used to test our hypothesis that wet-dry cycles in climate are as important to channel and sediment sequence development as sealevel change.

## APPROACH

In July-August 1998 aboard the *USNS Bowditch*, we collected sediment cores, CTDs and XBTs, 3.5 kHz subbottom profiles, and high-resolution 48-channel seismic profiles. This survey covered as much of the Gulf as possible given the restrictions that reefs, oil fields and territorial limits have on ship operations. The approach was to seismically map Neogene stratigraphy and tie this structure to dated surface sediment cores and industry wells where possible. The survey was a joint program between WHOI and NAVOCEANO.

## WORK COMPLETED

1. Data collected during the 1998 field program were shipped to Woods Hole during late 1998 and early 1999. Processing of this data is still in progress.
2. Water column data (XBTs and CTDs) were compiled and compared with winter conditions observed in February 1977 to provide a description of water mass types, temporal variability, and temperature and salinity conditions at the seafloor (Swift et al. 1999).
3. Processing of the 48 channel seismic data includes velocity analysis, deconvolution, and stacking and has been effective in removing water bottom multiples (Figure 1). This work is ~3/4 done.
4. Physical properties were logged on intact sediment cores. The cores were then split, photographed, and described. Core top and bottom samples were taken from all cores, and stratigraphic samples were taken from several cores. Preliminary measurements of stable isotopes on *Elphidium* sp. and calcium carbonate content have been made.
5. Water depth soundings on small-scale navigation charts were digitized and compiled to provide a publishable digital bathymetric database for the Gulf.

## RESULTS

### Oceanography

The oceanography of the Arabian Gulf profoundly affects the composition of the bottom sediments and their accumulation patterns with time. We need to understand the variability in water mass properties at the present time and the relationship between water properties and stable

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isotope ratios in surface sediments to effectively use isotope stratigraphy in sediment cores for correlating and dating purposes. With this motivation, we compiled data from 204 XBT casts and 87 CTD casts made on the *USNS Bowditch* cruise legs in July and August 1998 and compared these results with winter conditions defined by data collected by P. Brewer in February 1977. The important findings are (1) discovery of a year-round, sloping density front separating the deepest water in the Gulf (formed in winter) from the Straits of Hormuz (Figure 1), (2) discovery that near-bottom outflow through the Straits in summer is comprised of water mixed along the front and is not a current of the most dense water remaining in the basin, and (3) the first field evidence for eddies.

In summer, the seasonal thermocline separates a mixed surface layer (10-18 m thick, 29-36°C) from cold (20°-21°C), salty (39.4-39.8‰) deep water formed in winter (Figure 2). The upper layers are mixtures of warm, relatively fresh Gulf of Oman surface water, deep water, and a water mass component with high salinity and high temperature formed in summer near the Straits. The highest salinity values occur in 5-15 m thick layers at 20-40 m depth within cold-core eddies in the northwest end of the Gulf. River discharge has little effect in summer. Between July and August, the thickness of the mixed layer decreased by 3-4 m while its temperature increased by 3-4°C on average and by up to 8°C locally. During the same time the thickness of the thermocline increased by 10 m and the overall temperature increased by 2°-3°C. Lateral changes in thermocline temperature of up to 4°C occur over distances as short as 9 km. Long-wavelength variations in the thickness of the thermocline of 10-30 m occur over 45-90 km changing the thickness of the bottom water layer. These features appear to be eddies or meanders in a slow-moving bottom water flow out of the Gulf. Deep water is isothermal and changes little on weekly and seasonal time scales.

In winter, the Gulf is cooler by 9-17°C, saltier, and denser. No thermocline exists, and salinity varies over a wide range. Water in the Straits is separated from Gulf water by a distinct, year-round density front whose isobars intercept the seafloor 45-200 km west of the tip of the Musandam Peninsula. The front extends to the seasurface in winter but only to the top of the thermocline in summer (Figure 2). Bottom water in the Gulf north of the front is formed in winter, but exchange across the front occurs throughout the year. The front shallows to the west and appears to move eastward closer to the Straits in winter consistent with higher rates of bottom water production when air temperature cools. Neither summer nor winter survey found evidence in the Straits of Hormuz or its approaches for deep water formed in the Gulf during winter. It is likely that this dense bottom water mixes across the front to form a separate water type that flows out of the Gulf through the Straits of Hormuz, but we can not exclude the possibility that flow out of the Gulf is sporadic during the year or occupies a cross-section of the Straits that is small enough to have been missed by sampling. Outflow in spring and summer is balanced by relatively fresh surface seawater from the Gulf of Oman flowing northwestward to the head of the Gulf. Outflow in winter may be diminished because surface water must flow into the Gulf against the strong northwest Shamal winds.

Compiling temperature and salinity data for July 1998 and February 1977, we identify three principle water masses in the Arabian (Persian) Gulf (Table 1). Gulf Deep Water (GDW) forms only in the winter but remains in the deeper regions of the Gulf throughout the year. Indian Ocean Surface Water (IOSW) flows in from the Gulf of Oman at the seasurface only in summer. Summer Hormuz Water (SHW) forms in shallow water along the margins of the Arabian Gulf in spring or summer. To the west of the density front (53°-54°E), cold (20°-28°C) High Salinity Spikes (HSS) appear as 5-15 m thick layers with high (>40‰) salinity near the base of the thermocline, whereas warmer (>30°C) SHW to the east reaches a thickness of >40 m and

makes up most of the thermocline. The front is a year-round feature separating GDW from warmer, less saline water in the western approaches to the Straits of Hormuz. We could find no evidence for flow of GDW out of the Gulf in July 1998 either as a channeled bottom current or as a contour following geostrophic current.

Table 1. End member characteristics of the principal water masses in the Arabian Gulf.

Water Mass	Temperature (°C)	Salinity (‰)	Potential density ( $\sigma_\theta$ )	Sound Speed (m/s)
Indian Ocean Surface Water (IOSW)	32-34	36.5-37.5	21.5-22.5	1550-1555
Summer Hormuz Water (SHW)	33	39.8-40.5	24-25	1536-1557
Gulf Deep Water (GDW)	20-21	39.4-39.8	28.0-28.5	1527-1530
High Salinity Spikes (HSS)	20-28	39.8-40.6	26.0-28.0	1527-1548

#### Sediment cores

Based on our experience with the 1977 *R/V Atlantis II* cores, we used density logs and lithology to identify 10 cores that appear to penetrate the Last Glacial Maximum. Preliminary results suggest that the Holocene deltas off Iran were deposited in periods of time. At the bottom of one core close to the Tigris –Euphrates Delta, we found cross-bedded fluvial deposits. An age date for the marine deposits overlying these sediments will be an important constraint on the sea level history of the basin.

#### High resolution seismic survey

The seismic profiles show that the thick, asymmetric, Plio-Pleistocene basin wraps around the southwest corner of Iran and into the western approaches to the Straits of Hormuz. This indicates that the Straits waterway is maintained by subsidence driven by the southwestward propagating Zagros Mountain fold belt and is tectonically similar to the main NW-SE oriented Gulf basin. In addition, the seismic profiles and the 3.5 kHz data indicate that the upper layers in the basin are largely comprised of fluvial sediments shed from Iran (Figure 1). With the exception of the Holocene section along the Iranian coast where Uchupi mapped deltas up to 80-90 km long and up to 50 m thick, marine deposits appear to be minor. The fluvial sediments appear to originate in Iran and not from the Tigris-Euphrates river system. We can trace shallow reflectors beneath shallow water carbonate banks and interpret these banks as Holocene features.

### **IMPACT/APPLICATIONS**

In the Gulf, spatial variations in speed of at all water depths is generally 1521-1530 m/s in winter except on the Tigris-Euphrates-Karun delta where speed drops to as low as 1514 m/s. In summer, surface water speed is 1549-1555 m/s and decreases to 1527-1532 m/s between water depths of 15 and 50 m. In deeper water basins of the Gulf (>50 m depth), sound has the same velocity (1527-1529 m/s) throughout the year. Sediment velocities suggest that acoustic bottom loss in regions of silty clay along the Iranian coast is seasonally dependent, whereas bottom loss elsewhere in the Gulf is independent of season. Shallow carbonate banks appear to have no sound velocity anomaly below the seafloor baselevel surrounding the bank.

## TRANSITIONS

One of our primary goals is to obtain interval velocities from the 48 channel data. These will be compared to refraction velocities from the sonobuoys determined by J. Diebold at LDEO, to well velocities, and to acoustic velocities measured in sediment cores by NAVOCEANO. These data will provide direct, systematic measurements of seafloor velocity data base for Navy operations in the Persian Gulf. Another objective of the regional mapping will be to determine the location and depth of sub-seafloor channels. The digital 3.5 kHz data collected will be used to examine the nature and origins of seafloor micro-topography in the Straits of Hormuz.

## RELATED PRODUCTS

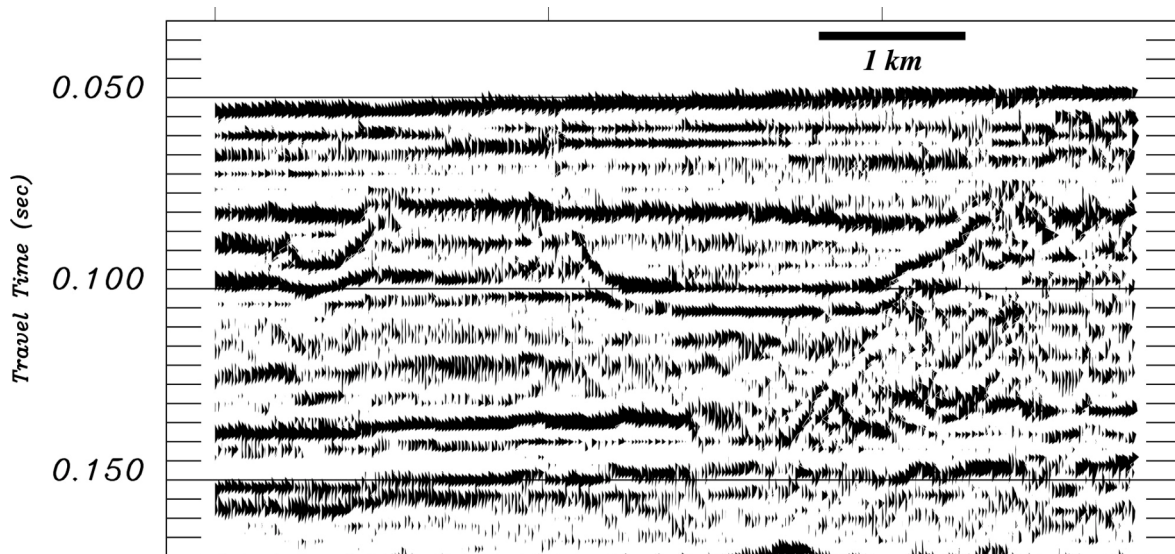
The high-resolution seismic and seafloor mapping study will provide an arid environment end-member to the STARTIFORM field studies.

We are sharing results with Amy Bower (WHOI PO Dept) who is studying Arabian Gulf bottom water outflow and Gulf water masses using publicly available NAVOCEANO data bases.

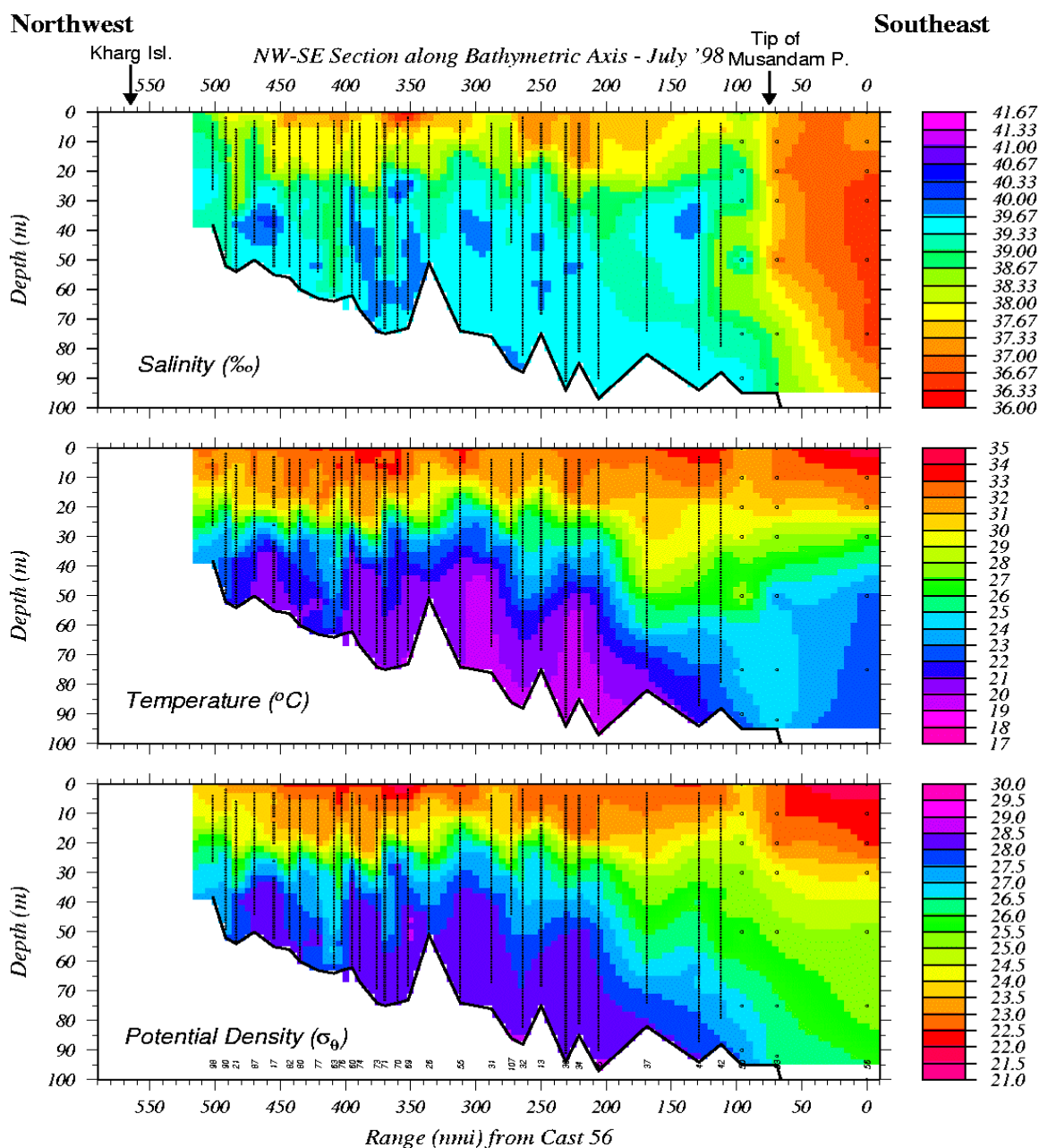
## PUBLICATIONS

Uchupi, E., S.A. Swift, D.A. Ross, 1999, Late Quaternary stratigraphy, paleoclimatology and neotectonism of the Persian (Arabian) Gulf region, *Marine Geology*, 160, 1-23.

S.A. Swift, E. Uchupi, and D.A. Ross, 1999, Water Mass structure in the Arabian (Persian) Gulf, WHOI Technical Memorandum 02-99, June 1999, 67 pp.



*Figure 1. Stacked seismic section, oriented NW-SE, shows two adjacent fluvial channels between 0.080 and 0.100 sec depth. Reflector sequences in the 3.5 kHz record here indicate that the fill in the channel is also fluvial. The layer above the channels (upper 26-30 msec) is one of the Holocene deltas extending southeastward off the Iranian rivers.*



**Figure 2.** A section from the Straits of Hormuz (right) to the head of the Gulf (left) along the deepest axis of the Gulf shows lateral variations of 10-30 m over 25-50 nmi (37-93 km) in the thickness of the thermocline. Depth to isotherm maps indicate that these variations are cold-core eddies. Note the front extending from the seafloor to the top of the thermocline between 90-180 nmi range. The front separates cold dense Gulf Deep Water from the Straits of Hormuz and is present year-round. Small dots indicate sample points. Small numbers above the lower axis are the station numbers. Data to the east (right) of 100 nmi are Niskin bottle data from August 1968, whereas the rest is CTD data from July 1998.